Sea Ice Surface Temperature Product From MODIS

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***Abstract*—Global sea ice products are produced from the Earth Observing System (EOS) Moderate Resolution Imaging Spectroradiometer (MODIS) onboard both the Terra and Aqua satellites. Daily sea ice extent and ice surface temperature (IST) products are available at 1- and 4-km resolution. Validation activities during the "cold period" (when meltwater is generally not present) in the Northern Hemisphere, defined here as October through May, have been undertaken to assess the accuracy of the 1-km resolution MODIS IST algorithm and product. Validation was also done at the South Pole station in Antarctica. In the Arctic Ocean, near-surface air temperatures from the National Oceanic and Atmospheric Administration (NOAA) National Ocean Service (NOS) Center for Operational Oceanographic Products and Services (CO-OPS) Alaska tide stations and from drifting buoys from the North Pole Environmental Observatory (NPEO) buoy program were compared with MODIS-derived ISTs. Using the standard MODIS sea ice product, which utilizes the MODIS cloud mask, results show a bias (mean error) of −2.1 K and a root mean square (RMS) error of 3.7 K. The negative bias means that the satellite retrieval is less than the air temperature. With the bias removed, the RMS error is 3.0 K. When additional visual cloud screening is performed to eliminate MODIS pixels thought to be contaminated by fog, results improved, with a subset of the larger dataset showing a bias of −0.9 K and an RMS error of 1.6 K. Uncertainties would be reduced in the Arctic Ocean dataset if the skin temperature of the sea ice were reported instead of the near-surface air temperatures. With the bias removed, the RMS error for the Arctic Ocean dataset is 1.3 K. Results from the South Pole station in Antarctica show that under clear skies as determined using lidar measurements, the MODIS ISTs are also very close to those of the near-surface air temperatures with a bias of −1.2 K and an RMS error of 1.7 K. With the bias removed, the RMS error for the South Pole dataset is 1.2 K. Thus, the accuracy (RMS error) of the IST measurement is 1.2–1.3 K. It is not possible to obtain an accurate IST from MODIS in the presence of even very thin clouds or fog, and this is the main limitation of the MODIS ice surface temperature product. MODIS sea ice products may be ordered from the National Snow and Ice Data Center in Boulder, CO.**

***Index Terms*—Advanced Microwave Scanning Radiometer-EOS (AMSR-E), ice-surface temperature, Moderate-Resolution Imaging Spectroradiometer (MODIS), sea ice.**

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I. INTRODUCTION

THE PRESENCE of sea ice influences the temperature and circulation patterns of both the atmosphere and the oceans. Sea ice reduces the amount of solar radiation absorbed at the ocean surface and, with the overlying snow cover, serves as an insulator, restricting exchanges of heat, momentum, and chemical constituents between the atmosphere and the ocean. Its large area coverage, 5% of the ocean surface, makes the sea ice cover a key parameter in the earth's energy balance. Ice surface temperature (IST) controls snow metamorphosis and melt, the rate of sea ice growth, and air–sea heat exchange and is an important parameter in large-scale modeling.

The importance of obtaining climate data records of sea ice in the form of high-resolution validated global sea ice maps is highlighted by recent studies showing decade-scale changes in the global sea ice extent. Several authors have shown that the extent of sea ice in the Arctic has decreased since 1979 by ∼3% per decade [1]–[3], while in the Southern Ocean the extent of sea ice increased ∼1% per decade from 1979 to 1998 [4]. More recently, from an analysis of a 30-year sea ice record, the rate of decrease in Arctic sea ice was found to be 20% greater since 1979 than since 1971, while the overall trend in the Antarctic was found to be negative over the 30-year period as a result of anomalously large ice extents in the early 1970s [5]. Most of these studies have used spaceborne coarse-resolution (∼25 km) passive microwave instruments to monitor the sea ice. Additionally, a warming trend in the Arctic has been measured using satellite-derived thermal-infrared data on surface temperatures [6].

Two classes of sensors—microwave and multispectral radiometers—are typically used for global mapping of sea ice extent, concentration, type, and temperature. The ability of microwave instruments, both passive and active, to collect data through cloud cover and polar darkness makes them well suited to global monitoring of sea ice extent and dynamics. Passive-microwave data can also provide a measure of near-surface ice temperature [7]–[12] though the location, at some depth within the snow/ice volume, that the temperature represents varies with ice type. However, microwave instruments cannot collect data on IST or sea ice albedo, and they have a relatively coarse spatial resolution that limits their utility for detailed studies of sea ice dynamics. In contrast, visible, near-infrared, and/or infrared sensors can provide detail on the ice extent and concentration during clear-sky conditions as well as on snow/ice albedo and IST.

The Moderate-Resolution Imaging Spectroradiometer (MODIS), flown on both the Terra and Aqua satellites (launched in December 1999 and May 2002, respectively), is useful for determination of sea ice extent, albedo, movement, type, and concentration at resolutions ranging from 0.25–1 km, and IST can be determined at 1-km resolution. Daily extent and IST map products are produced at the MODIS Data Processing System (MODAPS) facility at the Goddard Space Flight Center, Greenbelt (GSFC), MD, using MODIS data at 1-km resolution. The MODIS sea ice products were developed at GSFC and are archived and distributed by the National Snow and Ice Data Center (NSIDC) in Boulder, CO.

The purpose of this paper is to describe the algorithm used to create the MODIS IST maps, show examples of the IST products, and provide validation information for the algorithm and products during the cold period in the Arctic Basin and at the South Pole.

VI. Discussion and Conclusion

The 1-km MODIS IST product currently represents the only daily global IST product available at such a fine resolution and may be used in energy-balance modeling. The clear-sky limitation can possibly be obviated in the future using passive-microwave data in conjunction with MODIS data. Passive-microwave-derived ice temperatures are not directly comparable with ISTs because the passive-microwave temperature is an integrated measure of the temperature of the upper layers of the sea ice or/and overlying snow cover, and the depth from which the microwave energy emanates depends on the emissivity of the snow/ice. Maslanik and Key [29] developed a technique to combine AVHRR-derived ISTs with SSM/I data to derive IST. Though their temperatures appeared reasonable when compared with climatological averages, the absolute accuracy of the derived temperatures could not be determined.

However, following from prior work (e.g., [10] and [29]), if a relationship can be determined between MODIS-derived ISTs and AMSR-derived ice temperature, then the passive-microwave-derived ice temperatures can be used to approximate IST even through clouds. Such a product would provide modelers global IST data daily through cloud cover and darkness, though at a coarser resolution than is possible from MODIS alone.

With both the AMSR-E and the MODIS on the Aqua satellite, it is possible to assess the relationship between MODIS-derived IST and ice temperature derived from the AMSR-E. The recent launches of the AMSR sensors on the EOS Aqua and Advanced Earth Observing Satellite II spacecraft and the planned Defense Meteorological Satellite Program Special Sensor Microwave Imager/Sounder and the National Polar-orbiting Operational Environmental Satellite System missions will extend the sea ice records into the foreseeable future.

With regard to the "mixed-pixel problem," the presence of mixed pixels will not increase the overall error in ISTs significantly. The difference in surface emissivity for thin, bare ice or open water versus pack ice is small in the infrared part of the spectrum. So, the effect of the other surface types is that the surface temperature, and possibly the lower tropospheric humidity, will be higher. The IST algorithm is based on a wide range of temperature and humidity conditions, so this is taken into account to some extent. On the other hand, there can be a range of humidity conditions for a given surface temperature, even though these two parameters are physically tied together.

Additionally, thin ice near the buoy may cause the IST of the MODIS pixel to be unrepresentative. While a standard deviation of the ISTs of the adjacent pixel values would be good to determine, generally it is also possible to tell by looking at the ISTs of the nearby pixels that the ISTs are representative.

The MODIS sea ice products represent a suite of products that is useful as a component of a climate data record for sea ice extent and IST. Additional work will need to be done in order to validate the products in all seasons; however, the MODIS IST product appears to be of comparable or superior quality as compared to predecessor datasets, such as products derived from the AVHRR. (The Noise Equivalent Temperature differences for MODIS channels 31 and 32 and for the AVHRR infrafred channels were designed to be 0.05 and 0.12 K, respectively, at 300 K. Furthermore, the cloud masking with MODIS is an improvement over the cloud masking with the AVHRR.) Thus, the MODIS-derived products should compare well with products that will be derived from future sensors for determination of sea ice extent and IST.

The MODIS-derived IST provides an excellent measurement of the actual temperature of the surface of the sea ice during the Arctic cold period. Using cloud-free data as determined using the MODIS standard cloud mask (which includes some pixels affected by fog), the bias is -2.1 K with an RMS error of 3.7 K, and with the bias removed, the RMS error or accuracy is 3.0 K. However, under clear-sky conditions, two different validation studies from the clear-sky cases at the South Pole and in the Arctic Ocean show excellent agreement, with a bias of -1.2 and -0.9 K and an uncertainty of 1.7 and 1.6 K, respectively. With the bias removed, the RMS error or accuracy for the South Pole and the Arctic Ocean is 1.2 and 1.3 K, respectively.